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ANALYSES OF HEAT DISSIPATION TECHNIQUES FOR PROTECTIVE SHELTERS

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ABSTRACT

Seven cooling techniques were investigated and analyses were made to determine how practical each technique would be if incorporated into a 100-man shelter. The techniques were as follows: buried pipe grids using water as the heat transfer medium, a crushed rock heat sink using air as the heat transfer medium, vapor compression and absorption systems, well-water, ice storage utilizing mechanical refrigeration, compressed air, and liquid oxygen. Each system was examined with respect to the length of time it could be effectively operated, and its auxiliary requirements. None of the techniques appear to be satisfactory in all respects; however, the use of well-water is very attractive providing it is readily available at a cool enough temperature.

Since power requirements are closely allied with cooling systems the problems associated with power supplies are discussed.

The last section of the report is devoted to the total energy concept utilizing gas turbine package systems.

INTRODUCTION

This report constitutes a series of discussions on various methods of removing excess heat from personnel shelters. Although the discussions are confined to one type of shelter, the principles involved could be applied to almost any protective structure.

A standard steel arch building suitable for 100 men was assumed and the heat to be dissipated from men and equipment was estimated to be 22,000 Btu/hr latent heat and 22,000 Btu/hr sensible heat. Air inside the shelter was assumed to be at 90 DB (dry bulb) and 82 WB (wet bulb) with good circulation at all times. If a shelter is located in an area free of fire danger there is no need to consider a period when the shelter is completely sealed; however, some buildings will be built in potential fire areas and for these, a button-up period of 8 hours was assumed. Needless to say, this button-up period creates many problems, not only with heat dissipation but also with CO_2 removal and O_2 supply.

The first consideration given to any shelter is the amount of heat which can be dissipated to the soil directly through the shelter walls. The amount of heat which can be dissipated in this manner varies widely with time, temperature, moisture, and characteristics of the soil. The heat is absorbed by the soil at a decreasing rate, but calculations show that after 24 hours some soils would still absorb 44,000 Btu/hr. On the other hand, many soils would absorb much less. A separate report on this subject will be published at a later date, so for the following discussions the heat rejected to the soil through the shelter walls is neglected.

Another consideration is the amount of heat which can be removed by circulating fresh air through the shelter. This method of cooling has serious limitations since it depends on the temperatures of the outside air, but it can provide valuable supplementary cooling when conditions are favorable, particularly at night when the air temperature may be 20 degrees below that of the shelter. The method can be improved upon by drawing the air through a bed of sand or gravel. The cooling effect of sand is discussed more fully in TR-263, "Test of German Ventilation System"[1] and is mentioned in this report under the section entitled "Crushed Rock Heat Sink." Aside from the cooling effect of sand, which has not been fully explored, conventional air cooling is well known and although not discussed here in detail, it should be considered in all designs.

Heat dissipation as discussed in this report, is limited to specialized methods for short term cooling and other methods which will operate over long periods of time.

The removal of heat is so closely allied to the power supply that in most cases, the two must be considered simultaneously. Consequently, power generators are mentioned throughout the report and are also covered in a separate section.

WELL-WATER

Well-water, when available in sufficient quantity at a reasonable depth, makes an excellent heat sink. Figure 1 is a typical layout for a well-water system where the discharge water would be returned to the ground or sprinkled on the shelter roof. A sprinkler system used in this case would provide a measure of cooling for the shelter ground cover as well as washing away radioactive material. A hard surface or vapor barrier material would be required to prevent the radioactive particles from being carried into the soil.

Well-water maintains a remarkably uniform temperature throughout the year in any particular locality. It ranges from 42 degrees in North Dakota to 77 degrees in the southern tip of Florida, see Figure 2. This latter temperature would be too high for shelter cooling but in most places the temperature would be quite satisfactory. For example, a 100-man shelter with an inside condition of 90 DB and 82 WB with a sensible heat load of 22,000 Btu/hr and a latent load of 22,000 Btu/hr, would require a coil surface temperature of approximately 74.5 F. Water at 77 degrees could certainly not meet this requirement; however, water at 67 degrees with a 5 degree temperature rise through the coil would be satisfactory if the rate of flow was 17.6 gpm and the air flow across the coil was 1700 cfm. Air washers provide a more satisfactory method of heat transfer from air to water than coils when temperature differences are small and should be used if space is available. Well-water systems have three important characteristics: they are hand operable, they can be operated indefinitely both during and after the button-up period, and they provide water for drinking and washing. A supply of oxygen or compressed air would, of course, be needed during an extended button-up period, and a source of power for lights or cooking may be necessary afterwards. Such power requirements are small and might be handled by windmills erected after the blast (see section on Power Supplies).

Valuable information on underground reservoirs, the hydraulics of aquifers and other factors concerning wells can be found in References 3, 4, 5, and 6.

BURIED PIPES

A study was made to determine whether it would be practical to reject heat to the soil by circulating water through buried pipes which would form long loops extending 20 feet or more beyond the shelter walls.

The amount of heat which can be transferred from a long pipe to the soil depends primarily on the following factors: thermal conductivity of the soil, thermal diffusivity of the soil, time, temperature difference between soil and pipe, and the diameter and length of the pipe. The mechanical contact between pipe and soil is a secondary factor and the migration of moisture from warm soil to cooler soil can be important in some instances because it changes the thermal properties of the soil. Although heat transfer from buried pipes is recognized as a complex phenomenon, considerable work has been done theoretically and experimentally in designing pipe grids for heat pumps where the earth serves as a heat source. Ingersoll, et al[1] have derived the following equation which gives the heat transfer between soil and pipes of infinite length

$$q = k \, \Delta t \, F(Z) \qquad \text{where} \quad Z = \frac{\alpha t}{r^2}$$

$$\text{and } F(Z) = \frac{8}{\pi} \int_0^{\infty} \frac{e^{-ZB^2}}{J_0^2(B) + Y_0^2(B)} \cdot \frac{dB}{B}$$

q = heat transfer Btu per (hr) (linear ft)

Δt = temperature difference between the pipe and soil

k = thermal conductivity of the soil

α = thermal diffusivity of the soil

t = time

r = pipe radius

J_0 and Y_0 are Bessel Functions of the first and second kind respectively

B = variable of integration

Values of F(Z) have been calculated by Jaeger and Clarke[8] and Ingersoll, et al,[7]. Using Ingersoll's formula, calculations were made for two types of soil to illustrate how widely their characteristics can vary. Soil A was assumed to be a clay sand with 20% moisture, $\alpha = .045$ sq. ft. per hr. and $k = 1.74$ Btu/per (hr) (sq ft) (degree F, per ft). Soil B was assumed to be silty clay with 5% moisture, $\alpha = .011$ and $k = .17$. The problem was to determine how many feet of 2" pipe would be required to transfer 44,000 Btu/hr to the soil if $\Delta t = 10$ F and the system was to be in operation for 24 hours. The results show that 1240 fe-t of pipe would be required for Soil A and 10,100 feet for soil B. In many parts of the country, Δt might be 20 F or more, in which case the length of pipe would be reduced accordingly.

A satisfactory condition in the shelter depends, of course, on the temperature of the water as it returns from the piping system. As explained in the Well-Water section, the maximum temperature of the water for the shelter described in this report would be 74.5 F. Consequently, if the soil temperature was 50 F, the Δt between pipe and soil could safely be taken at 20 F if turbulent flow is maintained in the pipe.

It is quite possible, therefore, that 600 feet of 2" pipe in soil A could transfer at least 44,000 Btu/hr for the first 24 hours and at the end of two weeks it could still transfer 30,100 Btu/hr. The cost of installing 600 feet of pipe at a depth of 4 feet would be about $1300: $300 for the pipe and $1000 for the trenches..

If serious consideration was given to the adoption of this method it would be wise to facilitate calculations by plotting

$$\frac{U}{k} \quad \text{against} \quad \frac{\alpha t}{r^2} \qquad \text{where U equals Btu per (hr) (linear ft) (°F).}$$

G. S. Smith[9] has drawn this type of graph in designing a ground grid for heat pumps.

Although the buried pipe approach is potentially good in certain areas, the problem of pipe corrosion and susceptibility to ground shock must not be neglected.

Figure 3 illustrates one scheme where the heat would be transferred directly from the shelter air to the water. The splashing water sound should have a salutary effect on shelter occupants.

CRUSHED ROCK HEAT SINK

For short duration cooling a crushed rock or coarse gravel heat sink buried near the shelter could be used. The shelter air would be circulated through the rock and the total heat transferred would depend on the mass of the rock, its thermal properties and the temperature difference between rock and air. The rate of heat transfer would also depend on aggregate size, sink configuration, and air velocity.

The problem is quite complex but as a preliminary estimate, a heat sink suitable for a 100-man shelter might consist of a horizontal stack of 10 steel tubes 2 feet in diameter and 20 feet long with a header on each end, as shown in Figure 4. Each tube is filled with crushed rock. The heating load in a 100-man shelter, as outlined earlier, results in a sensible heat ratio of 50%, consequently, the rock must not exceed 75 F if it is to condense the moisture and remove the heat at a satisfactory rate. Assuming crushed limestone at a temperature of 65 F and an air circulation of 2000 cfm, it would be possible to maintain a satisfactory condition within the shelter for five hours. This is based on a rock temperature rise of 10 F which results in a total heat absorption of 216,000 Btu or an equivalent 18 ton-hours of cooling. This estimate is, of course, somewhat conservative since the rock will be steadily rejecting heat to the surrounding soil. It should also be mentioned that air pressure drop through the sink is important and would be a compromise with aggregate size.

Figure 4 represents a multi-purpose type of air system which can be operated both during and after the button-up period. The dampers can be set to meet the requirements of the shelter in accordance with the outside environment. The most useful arrangements are as follows:

a. During the heat of the day, outdoor air could be cooled by blowing it through the crushed rock before it entered the shelter.

b. During the night, cool air could be blown directly into the shelter and at the same time, cool air could be blown through the crushed rock to the outdoors preparatory for the next day's cooling.

c. Fresh air and shelter air could be mixed and blown through the crushed rock. This could provide adequate air circulation without bringing in excess fresh air during the heat of the day.

d. During the button-up period, the shelter air could be recirculated through the crushed rock. If the rock is saturated with heat and higher air velocities are desired, the shelter air could be recirculated through the fan only.

If circumstances were favorable for a crushed rock system and a more detailed analysis seemed justified, additional information can be obtained by studying the design of packed regenerators. The Chemical Engineers Handbook[10] gives a formula by Rummel and several references on regenerators.

Properties of some common rock are shown as follows:

Rock	Specific Heat	Specific Gravity
Granite	.195	2.67
Limestone	.217	2.53
Sandstone	.220	2.22

VAPOR COMPRESSION AND ABSORPTION SYSTEMS

Vapor compression and absorption systems, which are now widely used in air conditioning, have many advantages over other cooling methods. They can provide almost any desired condition with unlimited capacity and their cost per ton of refrigeration can seldom be equaled by any other method. The vapor compression system must, of course, be provided with power and the absorption system must be supplied with both heat and power. Table I and Figures 5 and 6 have been prepared to show a comparison between three arrangements assuming the use of air cooled condensers inside the equipment room. The first arrangement, Figure 5, which shows a refrigeration compressor in conjunction with an engine generator set utilizing ebullient cooling, results in the least amount of excess heat which must be removed from the equipment room with air. This is a very important factor since air circulation is directly related to the cost of blast closure valves, exhaust fan, and ducts. If water storage for ebullient cooling is not considered desirable, arrangement 1a (Table I) could be used with approximately 30 percent more cooling air. Arrangements 2 and 2a, which each combine an absorption unit with an engine generator set, require more cooling air but the generator set is smaller and would be somewhat quieter. The third arrangement, Figure 6, which combines an absorption system with wind-driven generators, would be almost silent except for fan noise. It would require a little less cooling air than the second arrangement but may be impractical because of the number of wind-driven generators needed and the requirement to erect them after an attack. Erection of wind generators is discussed briefly in the Power Section, page 9.

Many other arrangements are possible utilizing additional equipment such as evaporative condensers or perhaps using waste heat to operate the absorption unit. Such waste heat must be at a relatively high temperature and is usually obtained from waste steam or engine exhaust gases. The final section describes an integrated system where

gas turbine exhaust gases are used to generate steam for an absorption system. The ultimate design and selection of equipment, therefore, depends upon the requirements of the shelter in question and the ingenuity of the engineers.

ICE STORAGE FOR SHELTER COOLING

Buildings of limited usage such as churches and meeting rooms are frequently cooled by a system utilizing stored ice. In this type of system, the stored ice is the heat sink. The compressor making the ice is normally smaller than that required for full direct cooling since there is plenty of time to restore the ice between periods of usage. Most shelters fall into the category of limited usage buildings and can, therefore, be considered candidates for ice storage cooling.

There are several methods to consider for this type of system. For example, the condensing unit may be operated from an auxiliary power unit adjacent to the shelter or from a dependable outside source. In either case, cooling during a button-up period would be supplied by ice storage. After button-up, the compressor would operate as necessary to restore the ice for further emergencies and at the same time, meet the daily cooling requirements. The arrangement for these examples are shown in Figures 7 and 8. In Figure 8, the air cooled condenser, which would be preferred for this system, is shown in two locations. Prior to attack, it would be located inside the exhaust duct and after the attack it would be removed from this location and installed aboveground. The aboveground installation would require a small concrete slab with a blast-proof utility box containing "quick disconnect" fittings. Two men could carry the condenser outside and make the necessary connections in a few minutes.

Ice storage can also be considered when power will not be available from any source after attack, in which case the storage unit must be large enough to carry the entire load. The amount of cooling available, however, is limited to the practical size of the storage unit and economical considerations.

Table II gives the pertinent data on a number of commercial ice storage units. To determine which unit would be suitable for any given shelter, it is necessary to compute the required ton hours. For example, suppose a shelter needed 3 tons of refrigeration during twelve hours per day and it was felt necessary to provide sufficient ice storage for 2 days. The required ton hours would be

$$3 \text{ tons} \times \frac{12 \text{ hrs}}{\text{day}} \times 2 \text{ days} = 72 \text{ ton hours}$$

A glance at Table II shows that unit 'e', which is 9 ft x 5 ft x 4 ft, equipped with a 3-hp motor, would meet this requirement. The cost of this unit is approximately $4500.

COMPRESSED AIR FOR COOLING, POWER AND OXYGEN SUPPLY

Compressed air provides the basis for a useful multi-purpose system which during the button-up period can provide cooling, power and oxygen for a shelter. Calculations for a 100-man unit with a maximum button-up period of 8 hours has been investigated and the system shown in Figure 9 might be typical. Since air at 2400 psi can be obtained commercially in steel cylinders, this pressure was used in designing the air reservoir. To make full use of this potential energy, the air should be expanded into the shelter through a motor or turbine connected to an electric generator. The exhaust air would then enter the shelter at a very low temperature providing refrigeration and the power from the generator could be utilized or dissipated to the soil or atmosphere through resistance heaters. Because the use of such high pressure air with a relatively small motor (as would be required) does not seem practical, the system utilizes a heat exchanger preceding the air motor. If air was expanded into the shelter at the rate of 50 cfm through the heat exchanger and motor, the power generated would be approximately 1 KW and the total cooling would be about 0.7 tons. This cooling rate would be maintained until the pressure in the air reservoir dropped to 90 psi. The admission of 50 cfm of fresh air into the shelter would supply 1/2 cfm per person and assuming the shelter volume allowed 100 cu. ft. of space per person, the gas concentration after 8 hours would contain 2.5% CO_2 and 17.5% O_2. In addition, this air would keep a positive pressure in the shelter and act as a drying agent to reduce relative humidity. For the conditions outlined above, the reservoir would require 147 cu. ft. of air under compression for the 8 hours. To contain this air, two tanks which are 2 feet in diameter and 23 feet long could be used at an approximate cost of $4500 per tank.

The use of compressed air to supply refrigeration over long periods of time would not be economically feasible but for the initial button-up period it is unique. It could be combined with other systems which depend on outside air for ventilation.

LIQUID OXYGEN FOR COOLING AND BREATHING

The use of liquid oxygen to provide a coolant and oxygen for breathing would be impractical for most shelters. Where liquid oxygen is used as a regular part of an industrial or military operation however, it might well be considered, particularly for a button-up period. Such a system would consist essentially of an insulated storage tank located

close to the shelter in an underground room, or possibly buried in the earth. A vaporizer heat exchanger would be required inside the shelter with piping to the storage tank, as shown in Figure 10. The normal oxygen boil-off due to heat gain through the insulation would be vented through the heat exchanger keeping the shelter chilled before occupancy. During occupancy, liquid oxygen for cooling would be fed directly into the heat exchanger and gaseous oxygen for breathing would be released through a meter to the shelter atmosphere, since the amount needed for breathing would be less than that needed for cooling.

The gaseous oxygen would serve two additional purposes: it would maintain a positive pressure in the shelter and, being perfectly dry, it would help to reduce the humidity.

Cryogenic tanks with various types of insulations are readily available on a purchase or rental basis. Table III gives refrigeration and cost figures for a 700 cu. ft. tank insulated by two different methods and the much smaller 7 cu. ft. standard container. The cost figures for the large containers are quite high, substantiating the fact that liquid oxygen for shelters would not be practical for long term cooling, but the cost figures for the small tank suggest a practical short term system wherever liquid oxygen can be conveniently obtained.

POWER SUPPLIES

Power sources suitable for shelters include gas turbine generator sets, diesel or gasoline engine sets, windmills, solar cells, and thermoelectric units. Gas turbine generator sets are not suitable for small installations but they are very adaptable to integrated systems which are discussed in the next section.

Diesel or gasoline engine generating sets are available with outputs ranging from one kilowatt to hundreds of kilowatts. For the lower outputs they are very practical but for higher outputs they become bulky, heavy and less attractive as a power source. Like all fuel burning systems, they present some aggravating problems such as noise suppression, removal of exhaust gases and heat dissipation. Windmills, which might be considered when the power load is small, are quiet and produce neither heat nor noxious gases, although the accompanying batteries require a small amount of ventilation. They, too, however, have their disadvantages. It would be necessary to erect them after an attack and single windmills with outputs greater than 1 KW would be too bulky and difficult to handle without power lifting equipment. For low outputs, however, there should be no serious problem in hand-erecting small commercial units - one of which weighs 100 lb., uses a 5 ft. blade and produces 350 watts. Other disadvantages of windmills are their susceptibility to damage from a second attack and their higher initial costs.

Solar cells and thermoelectric units, which are not major sources of power, should be reserved for specialized low power applications.

THE GAS TURBINE TOTAL ENERGY CONCEPT

The integration of gas turbines into package systems which will provide power, heating and cooling, has been done successfully by several turbine manufacturers. These total energy packages, which have been installed in schools and other plants with multi-purpose demands, appear to be attractive for a group shelter arrangement.

In such systems, an electric generator is connected to the turbine to supply power and the hot exhaust gases are used to generate steam for heating or to operate an absorption system for cooling. The turbine also provides "bleed air" which can be used to operate pneumatic equipment such as air motors, ejectors for high volume vacuum cleaners, or ejectors for the removal of sanitary wastes.

Total energy systems now commercially available are in the 250 to 300 KW sizes. In this size range, the use of gas turbines becomes attractive because of their small size and light weight. Since all mechanical utilities must be suitably housed in underground blast proof buildings, it is important to minimize construction costs by selecting compact equipment.

While the generation of steam for heating is not normally expected for shelters, it would be a necessity if the shelters were to be used full time as offices or command centers at military establishments. A 300 KW unit can provide 2700 lb. of steam per hour at 15 psig.

To dissipate heat from shelters, the absorption unit on a 300 KW unit can provide approximately 150 tons of refrigeration.

With such quantities of steam and refrigeration available, it is not inconceivable that all incoming ventilation air could be sterilized and then cooled before being sent to the various shelters. This would reduce the hazards of BW.

The main problem associated with gas turbine total energy units, as with the internal combustion engine, is the removal of heat from the equipment room. Fortunately, the gas turbine rejects most of its heat to the exhaust gases at high velocity which can be discharged to the atmosphere through a relatively small opening. Internal combustion engines on the other hand, lose approximately 9 percent of their heat to the room by radiation and reject approximately 28 percent[11] to cooling water. The cooling water heat may be exhausted directly to the atmosphere if an ebullient cooling system is used, otherwise, large quantities of cooling air are required.

Figure 11 illustrates the group shelter arrangement where the rooms surround a utility hub which provides electricity, heating, cooling and other utility services. This building, which could provide shelter for approximately 2500 persons, could be used for a school or for offices and living quarters. The rooms form a complete circle with an enclosed sunken area in the center which could be used as an amphitheatre for outdoor activities. In view of the fact that the total energy systems provide air ejectors for cleaning and steam for sterilizing, this area could be easily decontaminated following an attack. The floor would be at least 7 feet below the top of the shelter ground cover, giving occupants radiation protection from the surrounding area.

The shelters and amphitheatre would be covered with a smooth non-combustible surface such as concrete, to assure no fire hazard and thereby obviate the necessity of preparing for a long button-up period.

Many problems involved in building shelters and concern about heat removal could be greatly alleviated if shelters were designed as permanent buildings with cooling a regular part of the mechanical services. Long range planning is needed.

SUMMARY

Table IV compares the systems outlined in this report with respect to five salient factors. None of the systems is satisfactory in all respects; however, well-water is probably most attractive because it can be used at all times and can be operated by hand. In many localities it would be the least expensive, requiring very little maintenance. Unfortunately, well-water is not available in all areas and where the systems are adopted, their susceptibility to ground shock must not be overlooked.

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Table I. Vapor Compression vs Absorption Systems

Arrangement	Heat load in shelter	Electric power required	Heat load from fuel (diesel fuel and natural gas)	Heat to be removed from equipment room by air***	Air circulation through equipment room	Water required for ebullient cooling
1 Vapor compression with engine generator set (ebullient cooling)	44,000 Btu/hr	8.09 hp*	77,600 Btu/hr	70,888 Btu/hr	3280 cfm	2.5 gal/hr 420 gal/week
1a Vapor compression with engine generator set (air cooled radiator)	44,000	8.09	77,600	92,288	4270	none
2 Absorption unit with engine generator set (ebullient cooling)**	44,000	2.7	198,000	136,718	6300	.875 gal/hr 147 gal/week
2a Absorption unit with engine generator set (air cooled radiator)	44,000	2.7	198,000	143,888	6660	none
3 Absorption unit with wind generators	44,000	2.7	172,000	126,588	5860	none

*hp for refrigerating unit based on a COP of 3 (air cooled condenser)
**Absorption units with air cooled condensers require NH_3 as their refrigerant
***It is assumed that vapor from ebullient cooling systems and combustion gases can be rejected directly to the outside through insulated pipes.

Table II. Capacities of Commercial Ice Storage Limits

Unit	Max. ton-hours*	Dimensions ft.	Motor HP**
a	18	7 x 3 x 4	3/4
b	32	11 x 3 x 4	1-1/2
c	48	11 x 4 x 4	2
d	65	11 x 6 x 4	3
e	81	9 x 5 x 6	3
f	97	11 x 9 x 4	5
g	146	11 x 12 x 4	5
h	195	11 x 7 x 4	7-1/2
i	244	11 x 20 x 4	10
j	324	9 x 21 x 6	15
k	488	9 x 32 x 6	20

*The maximum ton-hours of cooling available from the various commercial units are based on a water supply temperature of 45 F to the cooling coil.

**Using smaller compressors than those shown is not recommended because of the problems of proper oil return to the compressor.

Table III. Liquid Oxygen Tank Data

Example	Tank size	Insulation	Liquid O_2 required for cooling ft^3/ton/8 hrs	Liquid O_2* boil off ft^3/day	Cost of* insulated tank	Monthly charge* to replace boil off
1	700	12" perlite	7.14	6.96	$20,000	$725
2	700	1-1/2" multi-layer aluminum foil and glass paper (vacuum)	7.14	1.73	30,000	263
3	7	Vacuum only	7.14	.2	645	21

*Data supplied by manufacturer

Table IV. Summary of System Capabilities

	System would be practical anywhere	System can be used during button-up	System would be practical for long duration	System can be operated without electric power	Additional requirements during button-up period
Buried pipes	No	Yes	possible	Yes*	O_2, LiOH
Crushed rock	No	Yes	No	Yes*	O_2, LiOH
Vapor Compression and Absorption	Yes	No	Yes	No	Cooling O_2, LiOH**
Well-Water	No	Yes	Yes	Yes*	O_2, LiOH**
Ice Storage	Yes	Yes	Yes	No	O_2, LiOH
Compressed Air	Yes	Yes	No	Yes	None
Liquid Oxygen	No	Yes	No	Yes	None

*Electric power desirable but not absolutely necessary.

**Well supplies water for drinking and washing.

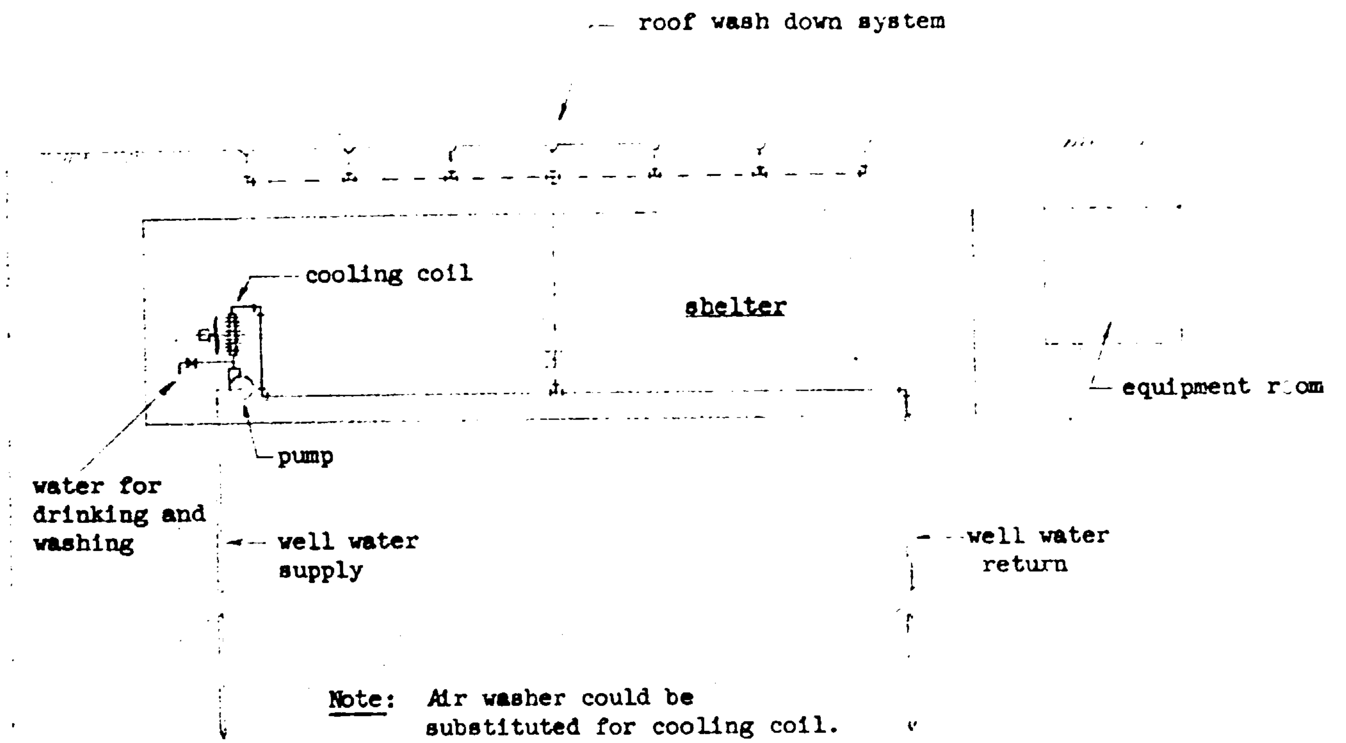


Figure 1. Well-water system with alternate water discharge.

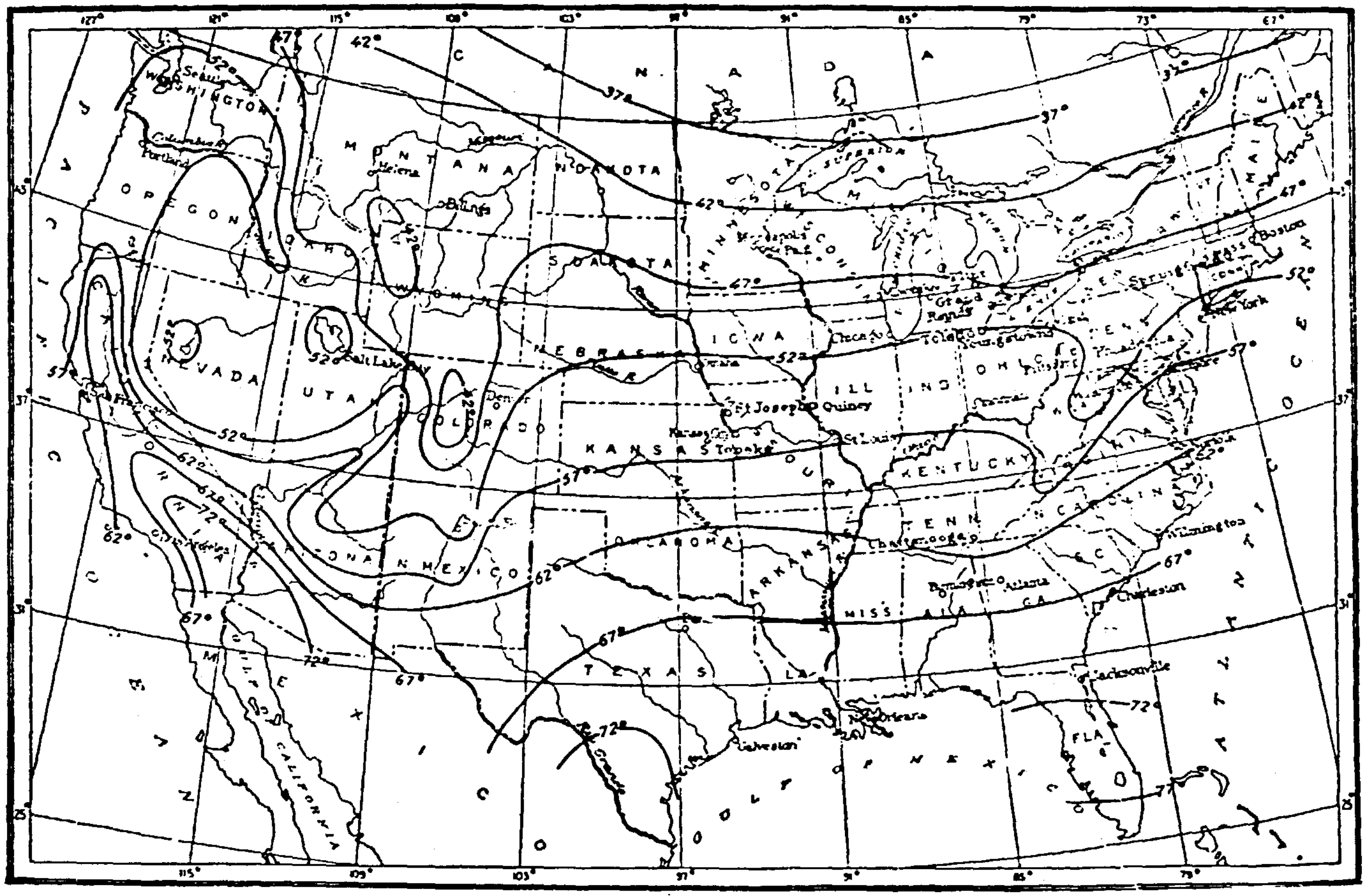


Figure 2. Approximate well-water temperature at depths of 30 to 60 ft.[6]

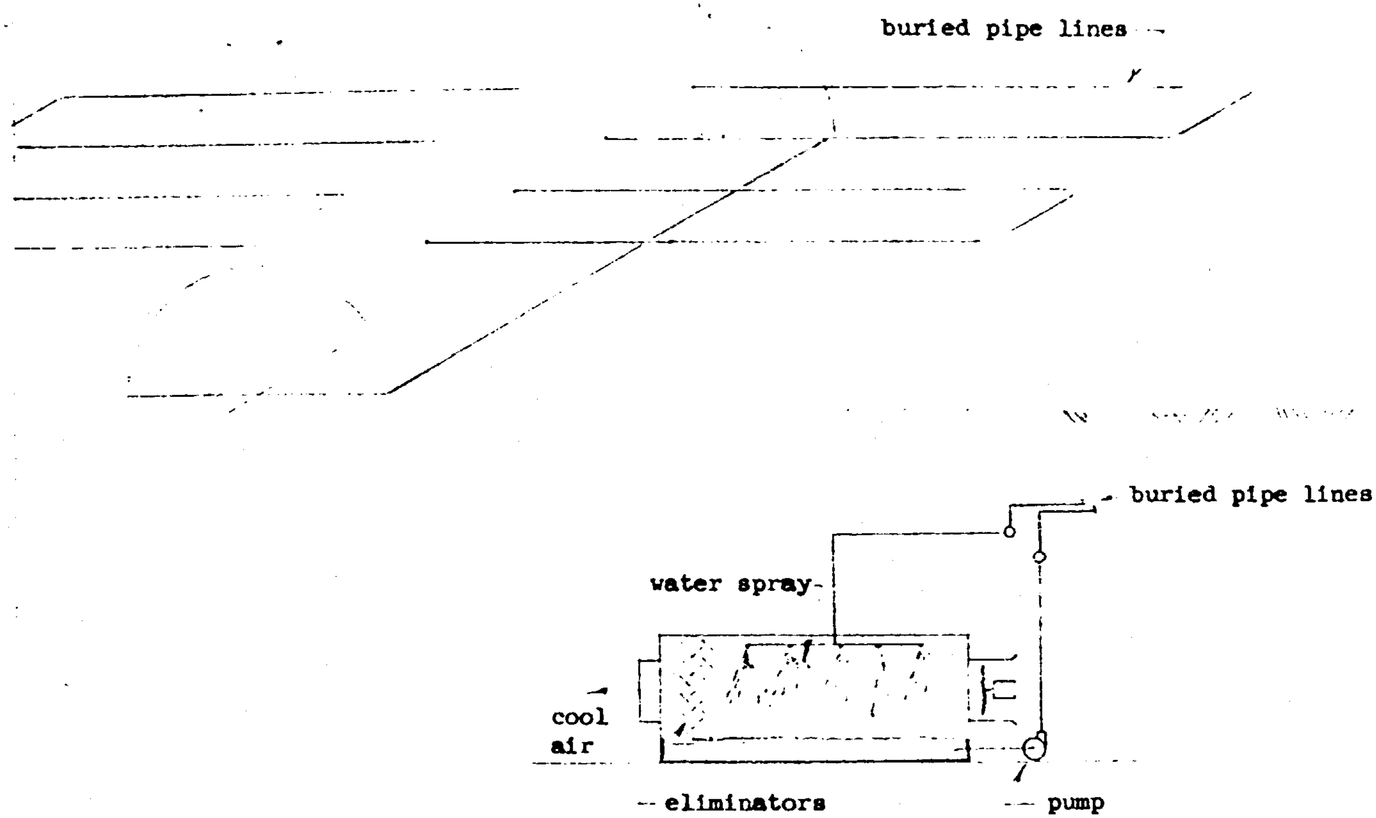
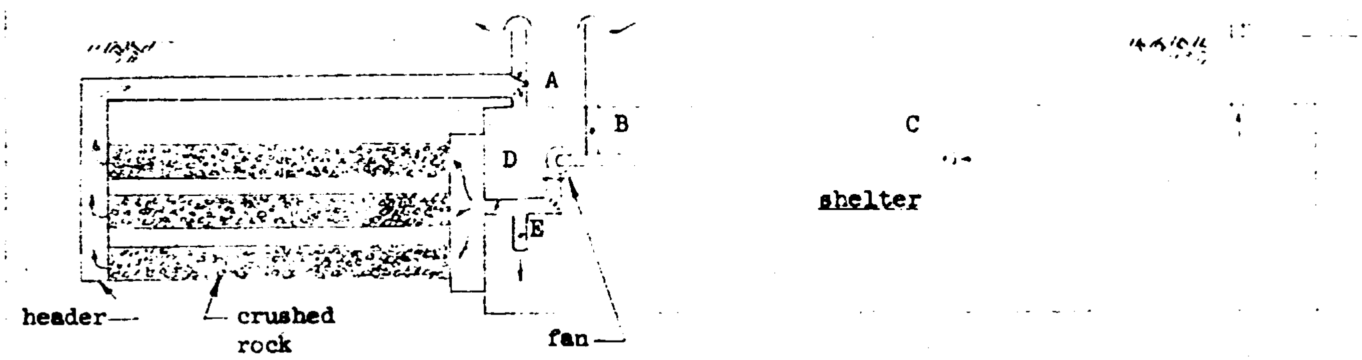


Figure 3. Buried pipe system.



1. A in top position. D and B open. C and E closed. Fresh air blows through rock into shelter.
2. B open, D and E half open, C closed, A in bottom position. Fresh air into the shelter and through rock to outside.
3. B and C half open, D open, A in top position, E closed. Fresh air and shelter air mix and blow through rock into shelter.
4. B and E closed, C and D open, A in top position. Shelter air recirculates through rock.
5. B and D closed, C and E open. Shelter air recirculates through fan only.

Figure 4. Crushed rock system.

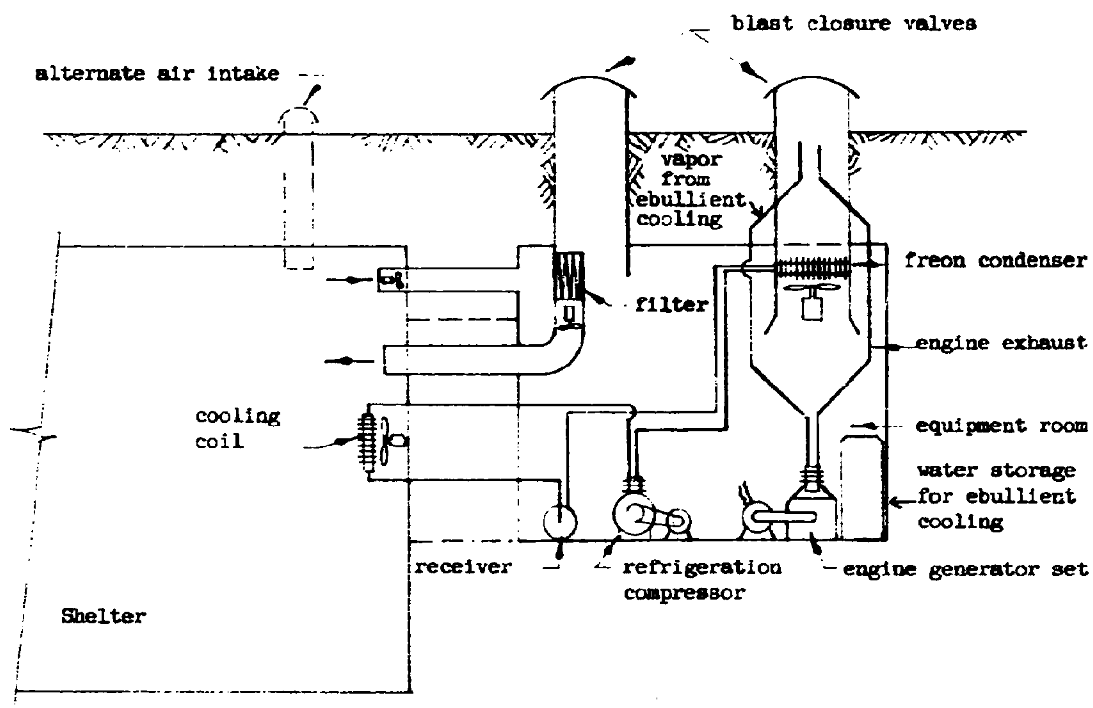


Figure 5. Vapor Compression Refrigeration System combined with an engine Generator Set.

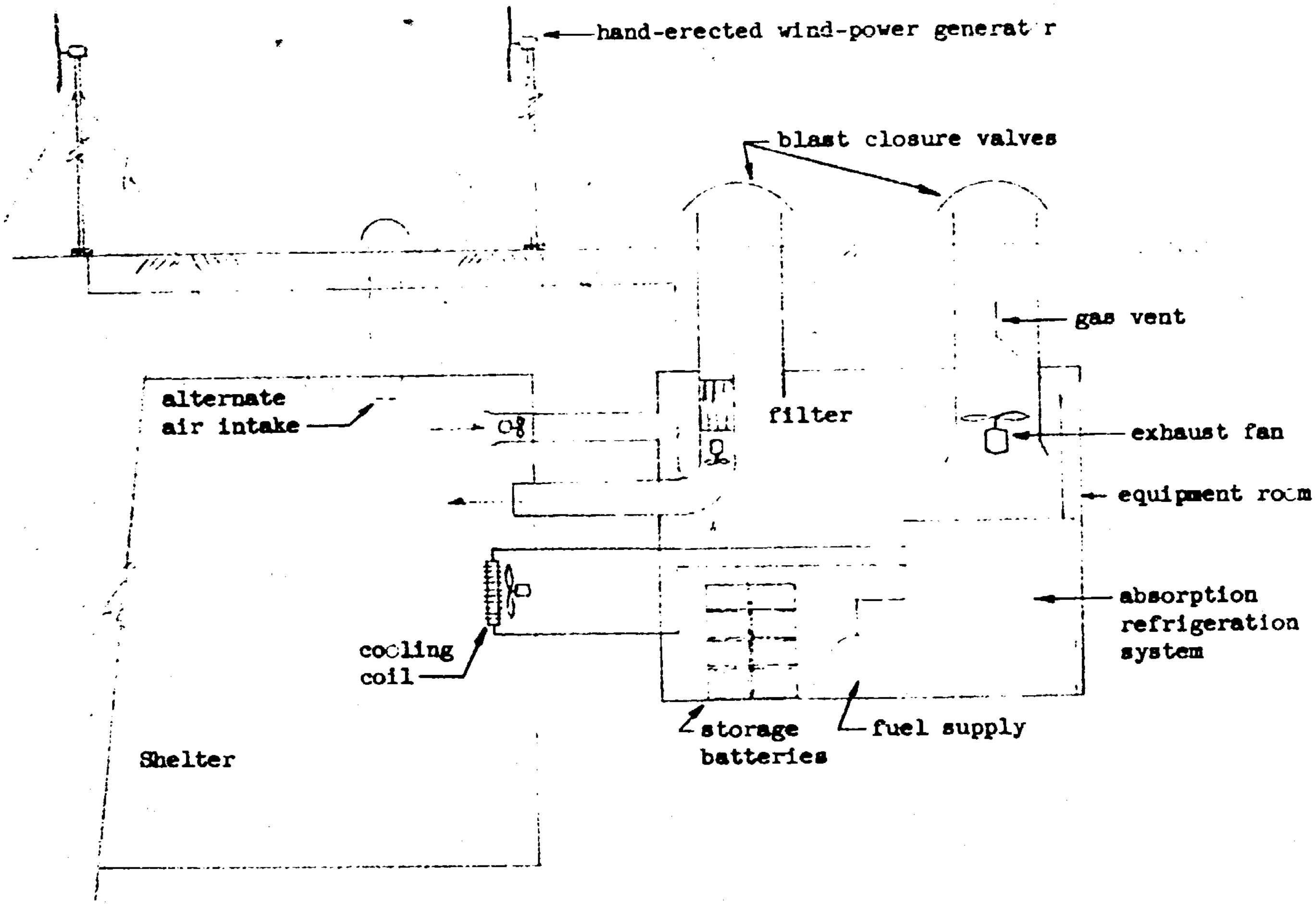


Fig. 6 Absorption Refrigeration System combined with Wind Powered Generators

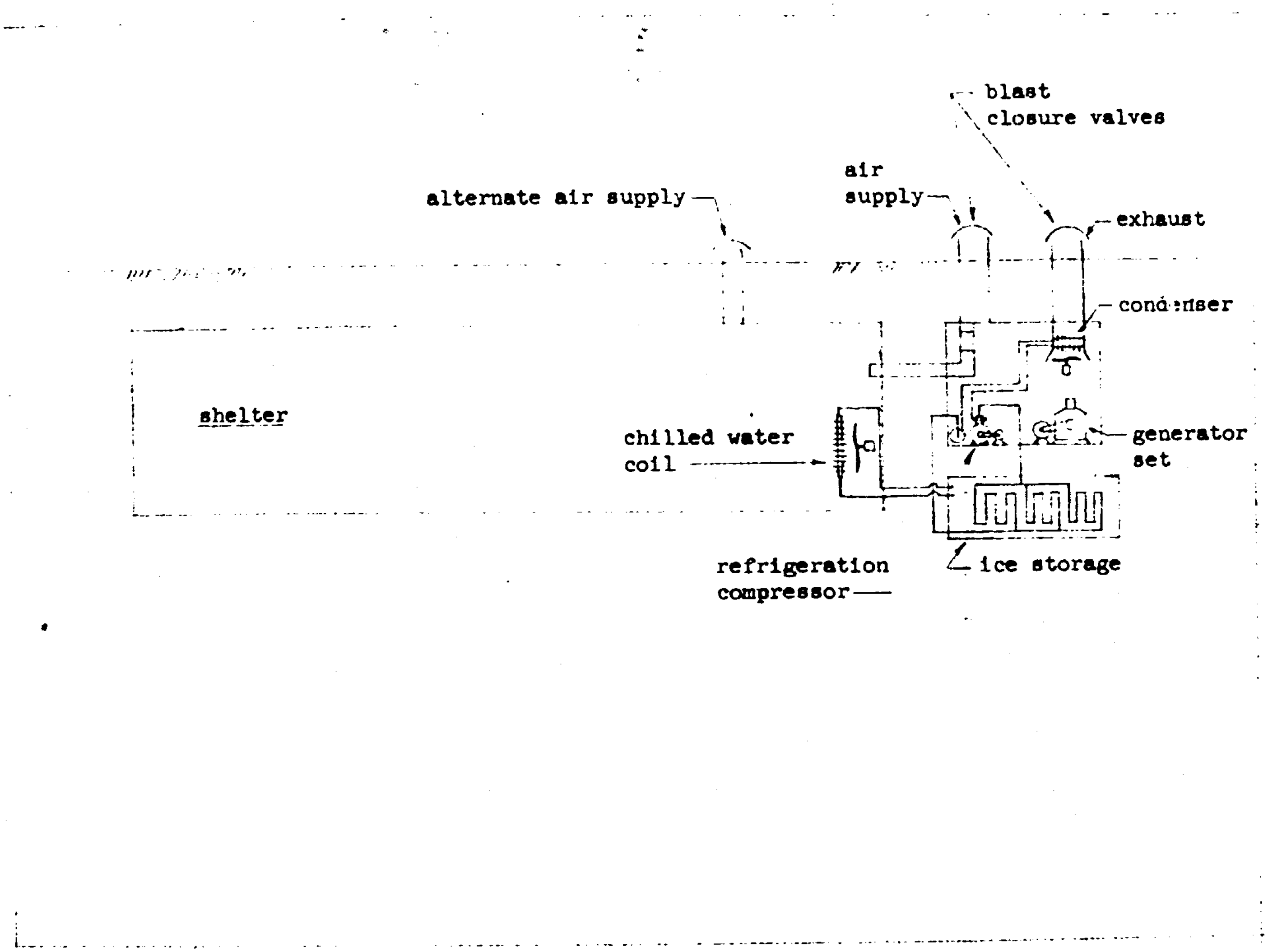


Figure 7. Ice storage system with auxiliary power supply.

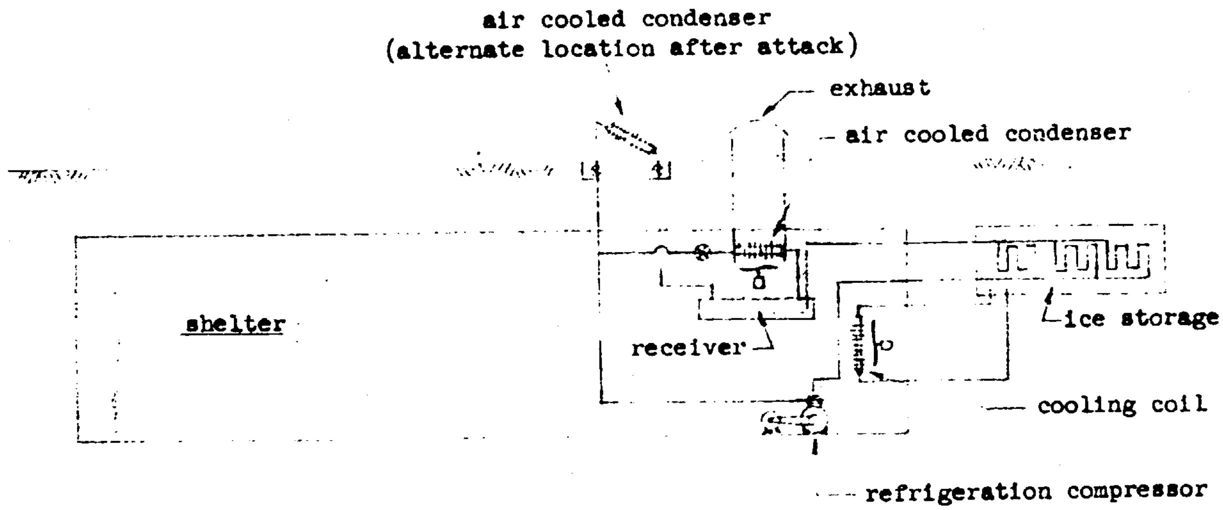


Figure 8. Ice storage system without auxiliary power supply.

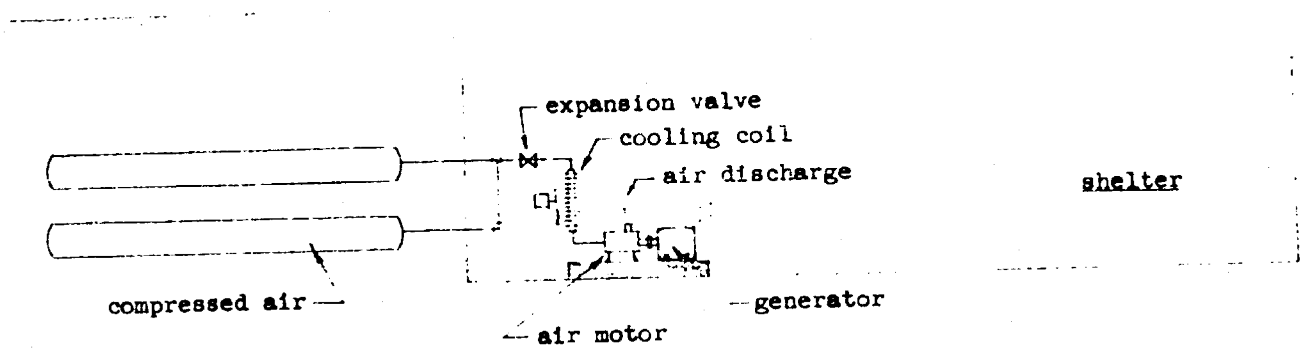


Figure 9. Compressed air system for cooling, power and O_2 supply.

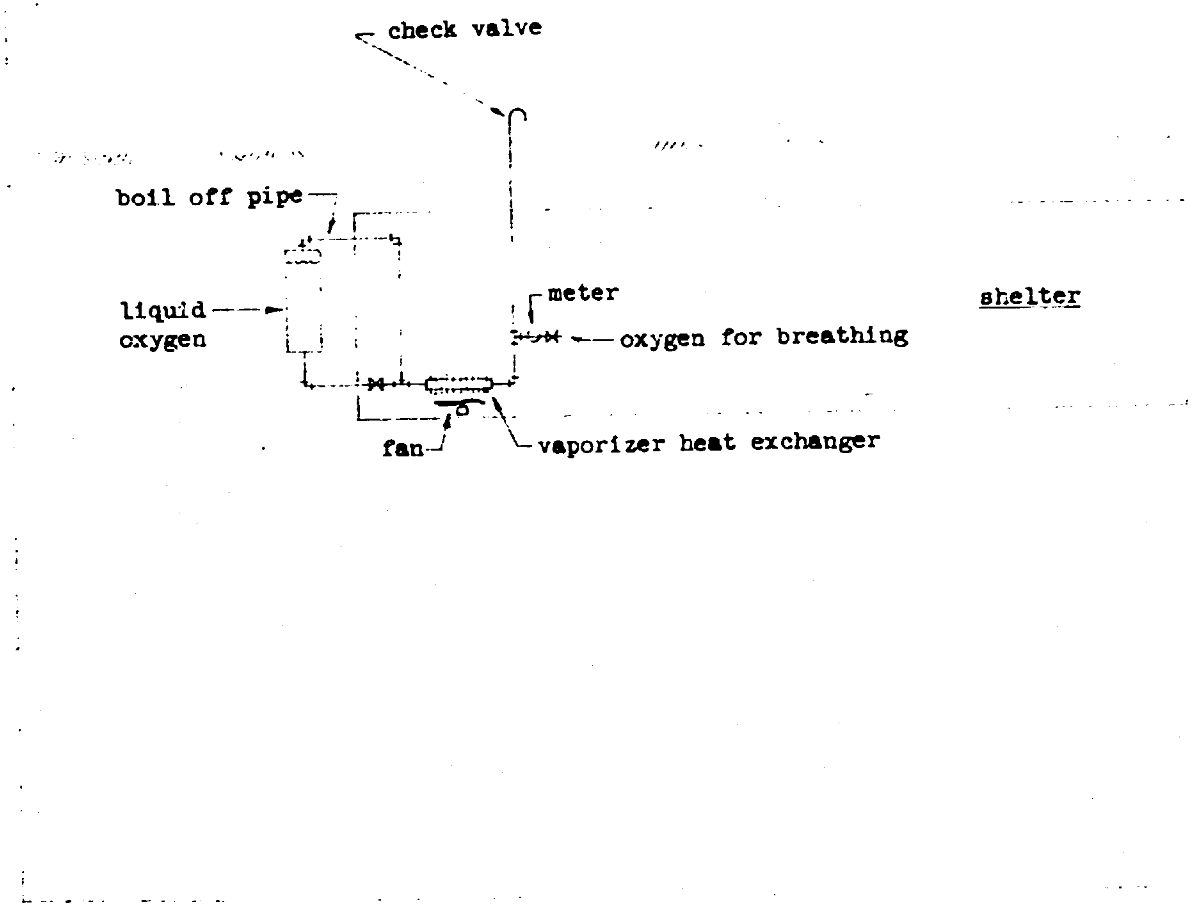


Figure 10. Liquid oxygen system.

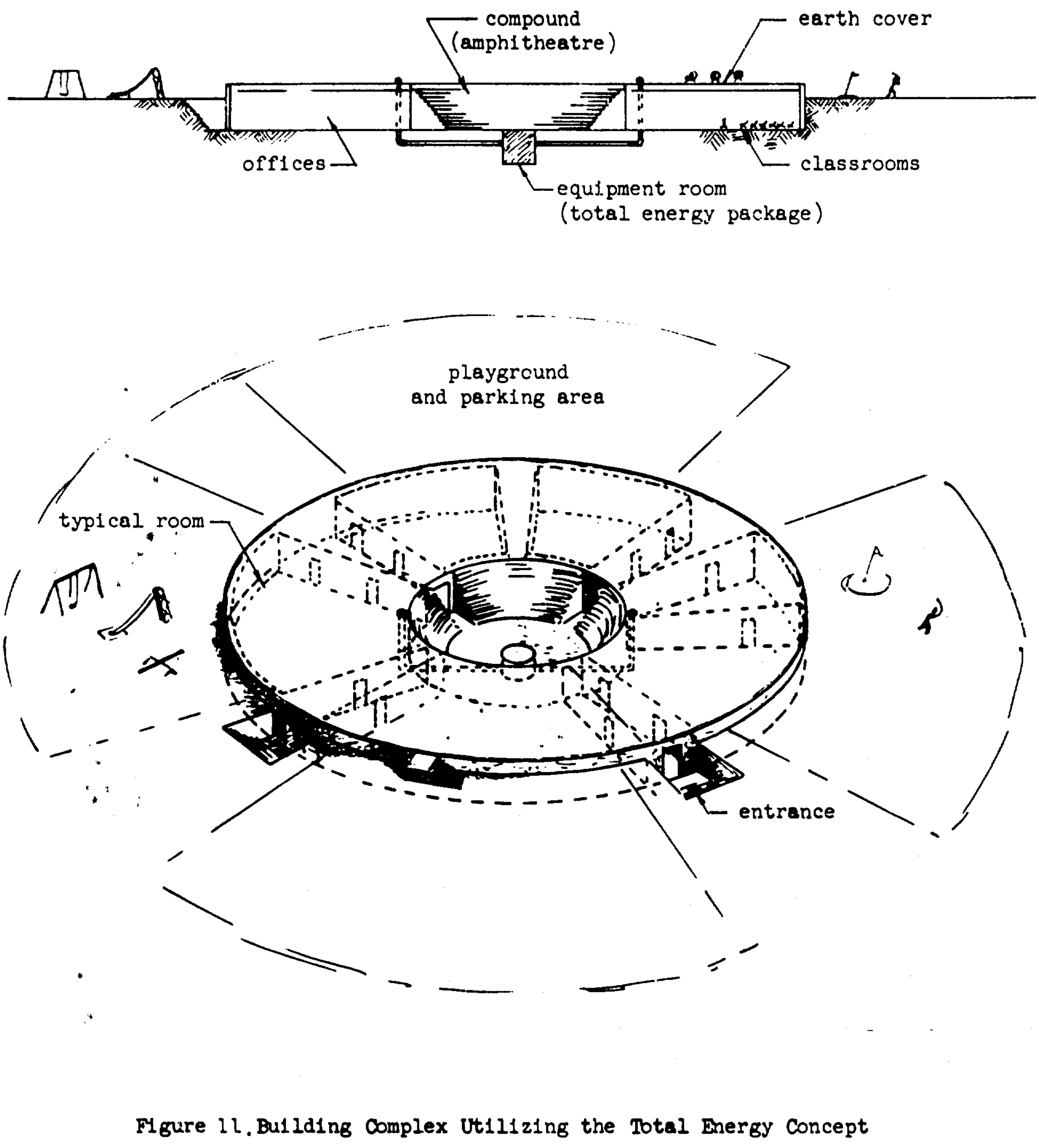


Figure 11. Building Complex Utilizing the Total Energy Concept